# An Alternative TESLA Damping Ring Lattice Design at Fermilab

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## Abstract

A new TESLA damping ring lattice design has been carried out at Fermilab. The motivation of the work is that: since kicker's rising time can be made much faster than falling time, so if we use a more compressed injection/extraction scheme (first suggested by J. Rogers from Cornell)*, the circumference of damping ring can be reduced significantly to about one-third of the original design. In this report, we present a linear lattice design to accommodate such injection/extraction scheme, some parameters have been discussed, and a primary dynamic aperture tracking result with linear wiggler effects is shown at the end.


## 1 Introduction

The first TESLA damping ring design has a circumference 17 km to accommodate a 1ms long contains 2820 bunches linac pulse. The restriction on the circumference is coming from kicker's rising and falling time. More detail study shows that the kicker's rising time could be reduced to around 5ns, therefore, the 2820 bunches can be compressed into 60 bunch trains with 47 bunches per train; the bunch spacing within a train is 6ns (harmonic of 500 MHz damping ring RF system); and the train length is 340 ns (harmonic of 1.3GHz linac RF system). The available kick falling time is 64ns (58ns for the last train), which we think it's not very critical to build. The injection/extraction scheme is shown in fig. 1.

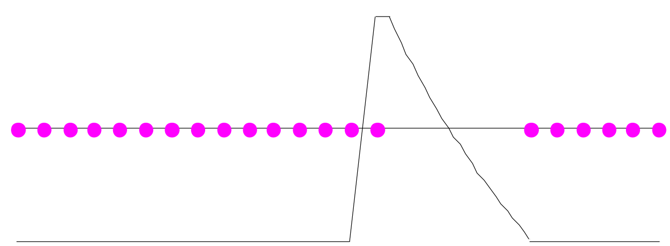

**Figure 1 Injection/Extraction Scheme for Fermilab Damping Ring**

With this consideration, we redesign the TESLA damping ring, the basic parameters are kept same with first design. We also did the dynamic aperture analysis include linear wiggler effects on this new lattice. The results shows that such a damping ring can be an alternative for TESLA.

## 2 Design Considerations

### 2.1 Circumference

We worked out our damping ring lattice design according to a common systematic approach[1]. The requirements/input parameters driving Fermilab damping ring lattice design are listed in Table 1[2]. The number of bunches per train $N_b = (T_t - 64)/6 + 1 = 47$, the total train number $N_t = N_{b,total} / N_b = 60$, and the circumference[1] $C = (T_t N_t - 6)c = 6113.97m$.

**Table 1: Input parameters for the Fermilab positron damping ring**

| | |
|---|---|
| Number of bunches $N_{b,total}$ | 2820 |
| Train to train spacing $T_t$ ns | 340 |
| Kicker rise time $\tau_{k,r}$ ns | 6 |
| Kicker fall time $\tau_{k,f}$ ns | 64 (58) |
| Cycle time $T_c$ s | 0.2 |
| Injected emittance $\gamma\varepsilon_{x(y)}$ m | 0.01 |
| Horizontal extracted emittance $\gamma\varepsilon_x$ m | $8\times10^{-6}$ |
| Vertical extracted emittance $\gamma\varepsilon_y$ m | $0.02\times10^{-6}$ |

### 2.2 Ring Energy

The desire to maintain high-spin polarization limits the choice of ring energy; the spin tune should be a half integer $a\gamma = n + 1/2$, $a \approx 1.16\times10^{-3}$. Considering damping time and instability issue, we choose energy E = 5.066 GeV, which makes n = 11.

### 2.3 Damping Time and Horizontal Emittance

Here, we choose the same damping time $\tau_y$, i.e. 28 ms, as TESLA design. The number of damping time is 7.2 and the equilibrium vertical emittance $\varepsilon_{ye} = 1.44\times10^{-8}$ m. The impact on vertical alignment tolerances has not been studied and will be carried out later. $\tau_y$ can be written as (1)[3]:

$$\tau_y = \frac{3C}{r_e c\gamma^3 I_2} = \frac{3C}{r_e c\gamma^3 (I_{2a} + I_{2w})} \tag{1}$$

[1] The last train is 340-6 ns long instead of 340 ns for inject/extract the next bunch in first train.

Here, C is the circumference, $r_e$ is the classical electron radius, c is the speed of light, $\gamma$ is the beam energy in units of $mc^2$, and $I_2 = \int_{dipoles} \frac{1}{\rho^2} ds = \int_{B\_arc} \frac{1}{\rho^2} ds + \int_{wiggler} \frac{1}{\rho^2} ds$ is the second synchrotron integral over dipoles.

The equilibrium horizontal emittance can be written as (2)[3], where $C_q \approx 3.84 \times 10^{-13}$ m, $J_x = 1 - I_4/I_2 \approx 1$ for separate function magnet, and $I_5 = \int_{dipoles} \frac{H}{|\rho^3|} ds$. Since the $\eta$ function at wiggler section is very small, we can assume that there is no emittance contribution from wiggler. $I_5 = \frac{2\pi \langle H \rangle_B}{\rho^2}$, and $\langle H \rangle_B$ is the average of the Courant-Snyder dispersion invariant over the arc bending magnets.

$$\gamma\varepsilon_x = \frac{C_q \gamma^3 I_5}{J_x I_2} \tag{2}$$

From formula (1), (2) and required damping time and equilibrium emittance in mind, we can determine $I_2$ and $I_5$. The arc cell is designed to meet $I_5$ requirement, and the wiggler section is designed to provide enough damping.

## 3 Linear Optics

We choose TME[4] lattice for Fermilab damping ring. The phase advance per arc cell is $150^0/90^0$ for the horizontal and vertical motion, respectively. Since for a "large" damping ring (compare with NLC damping ring and synchrotron light source) the equilibrium horizontal emittance is not a very critical issue, the choices have been made are coming from considerations of chromaticity correction, larger $\alpha_p$, and $\beta_{\max} \le 49$ m (we assume that the magnet pole radius is $r = 5\sigma_{inj} + 5mm = 40mm$).

The layout of the ring has been designed with sextant symmetry. There are total six long straight sections, and the wigglers have been installed in two of them. The other four long straight sections are designed with FODO cell. They are long enough and spared for the future accommodation of various injection/extraction schemes, which are discussed now among groups; RF cavities, and tune adjustment sections.

For the wiggler section, we use the NLC damping ring[5] wiggler model in our design. In order to reduce the wiggler effects on linear lattice, the average beta function in this section is about 6 m. Total 40 such wigglers have been used for positron damping ring. The total wiggler length is about 77m.

The lattice functions for different sections of the ring are shown in Figure2–7 below. The principle lattice parameters are listed in Table 2.

**Table 2: Principal lattice parameters (positron ring)**

| | |
|---|---|
| Energy E GeV | 5.066 |
| Circumference C m | 6113.967 |
| Number of bunches $N_{b,total}$ | 2820 |
| Number of Trains $N_t$ | 60 |
| Number of bunches per train $N_b$ | 47 |
| Train to train spacing $T_t$ ns | 340 |
| Kicker rise time $\tau_{k,r}$ ns | 6 |
| Kicker fall time $\tau_{k,f}$ ns | 64 (58) |
| Cycle time $T_c$ s | 0.2 |
| Injected emittance $\gamma\varepsilon_{x(y)}$ m | 0.01 |
| Horizontal extracted emittance $\gamma\varepsilon_x$ m | $8\times10^{-6}$ |
| Vertical extracted emittance $\gamma\varepsilon_y$ m | $0.02\times10^{-6}$ |
| Betatron tune $\upsilon_x/\upsilon_y$ | 56.584/41.618 |
| Natural chromaticity $\xi_x/\xi_y$ | -74.6/-55.4 |
| Momentum compaction $\alpha_p$ | 0.0014 |
| Maximum beta function $\beta_{x,max}/\beta_{y,max}$ m | 49/45 |
| Maximum dispersion $\eta_{x,max}$ m | 0.72 |
| Equilibrium horizontal emittance $\gamma\varepsilon_x$ m | $5.5\times10^{-6}$ |
| Equilibrium bunch length $\sigma_z$ mm | 6 |
| Equilibrium momentum spread $\sigma_e$ | 0.0015 |
| RF frequency $f_{RF}$ MHz | 500 |
| RF harmonic h | 10197 |
| RF voltage $V_{RF}$ MV | 27.2 |
| Number of particles per bunch $N_e$ | $2.0\times10^{10}$ |
| Current I mA | 443 |
| Energy loss per turn $U_0$ MeV/turn | 7.73 |
| Total radiated power $P_W$ MW | 3.4 |
| Number of vertical damping time $N_\tau$ | 7.46 |
| Damping time $\tau_x/\tau_y/\tau_e$ ms | 26.8/26.8/13.4 |

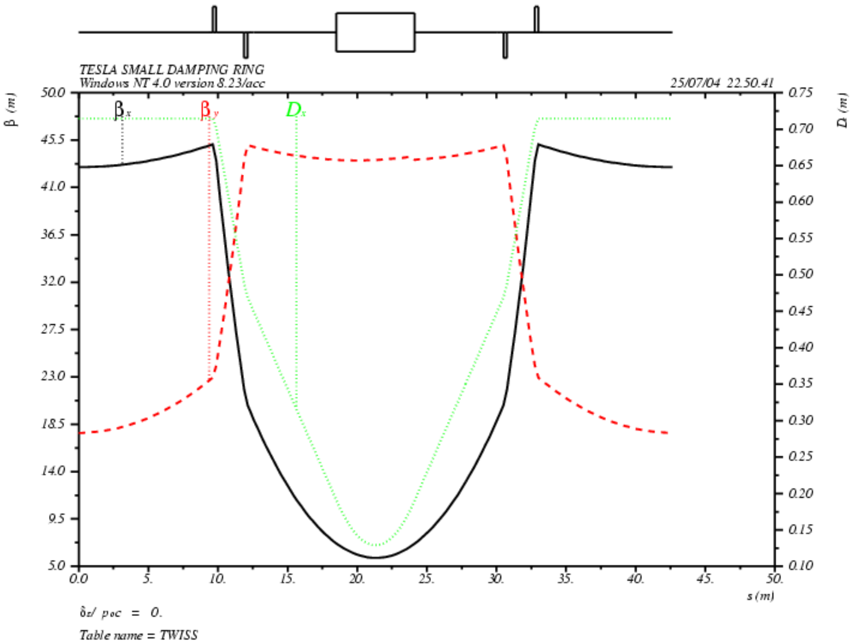


**Figure 2: Lattice functions in an arc cell.**

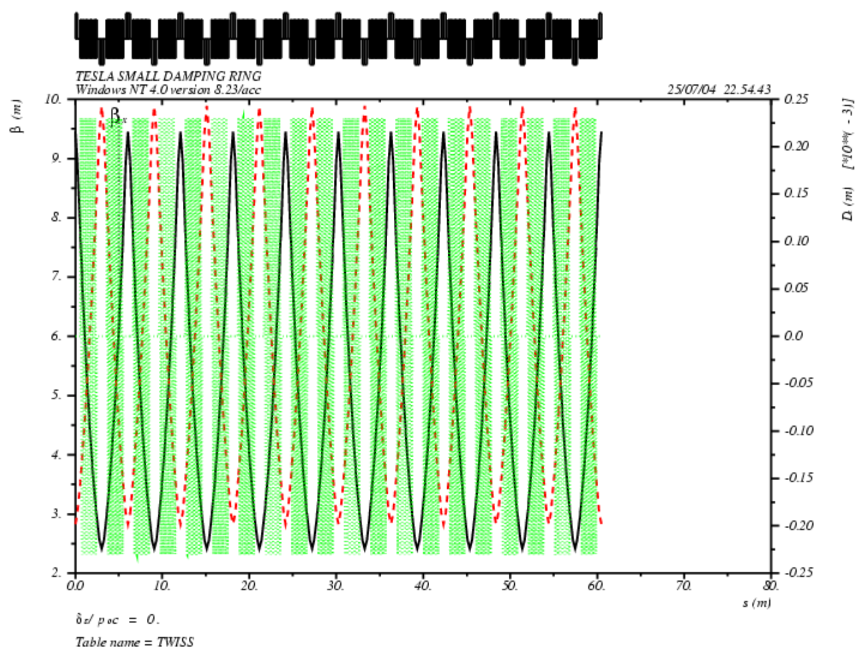


**Figure 3: Lattice functions for wiggler section**

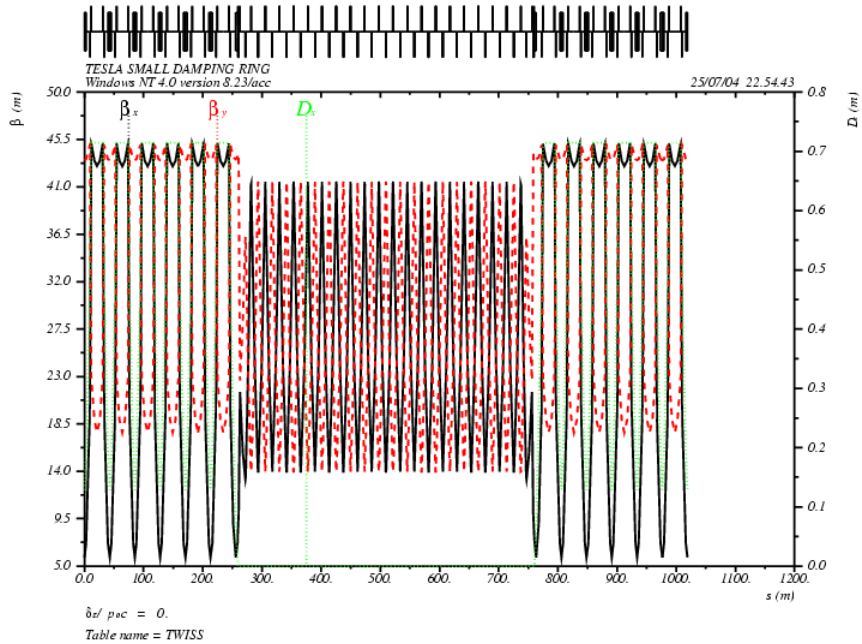


**Figure 4: Lattice function in normal sextant**

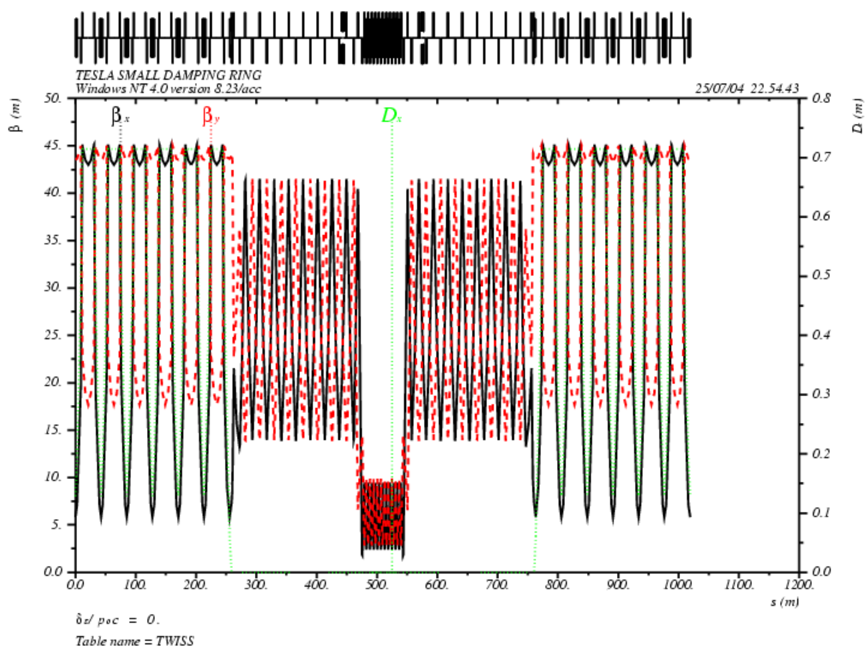


**Figure 5: Lattice function in wiggler sextant**

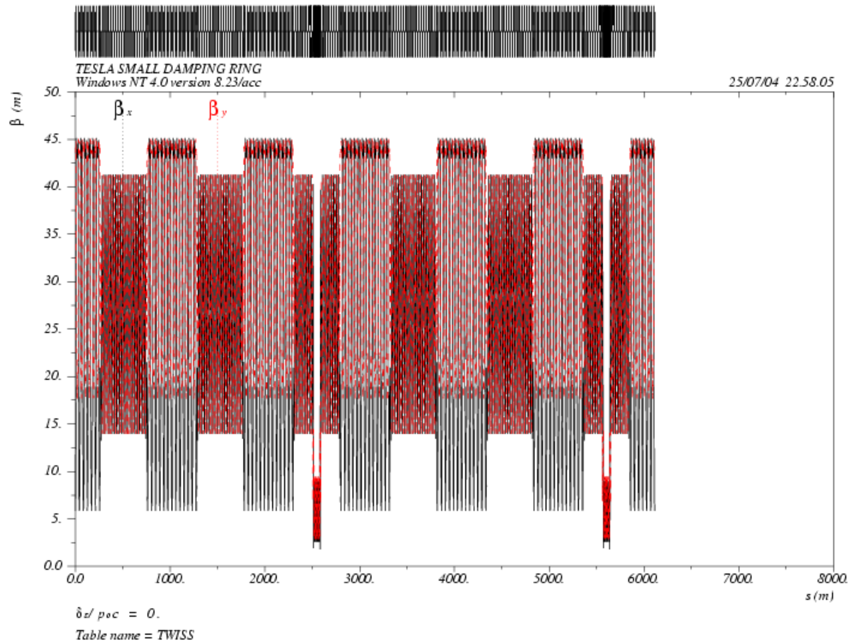


**Figure 6: Beta functions for the entire ring**

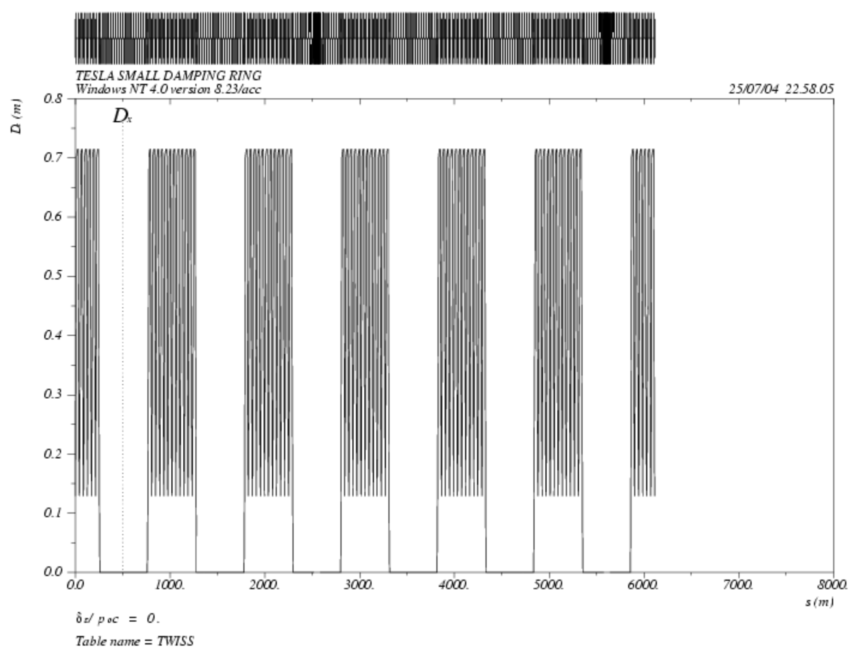


**Figure 7: Dispersion function for the entire ring**

## 4 Chromaticity Correction and Dynamic Aperture

The phase advance per arc cell is $150^0/90^0$ for the horizontal and vertical motion, respectively. There are 12 such cells per arc. Therefore, every two cells in vertical plan the phase advance is $\pi$, and every six cells in horizontal plan the phase advance is $5\pi$. This kind of arrangement helps to reduce second order geometric aberrations introduced by sextupoles. At present only two family sextupoles SD and SF are installed in arc cell and be adjusted to give zero first-order chromaticity. The variation of tune with momentum spread ±1% is shown in Figure 8, and the working point in tune space with ±1% energy spread is shown in Figure 9. The tracked horizontal and vertical phase space are shown in Figure 10. The dynamic aperture with linear wiggler effects has been studied and the results are shown in Figure 11.

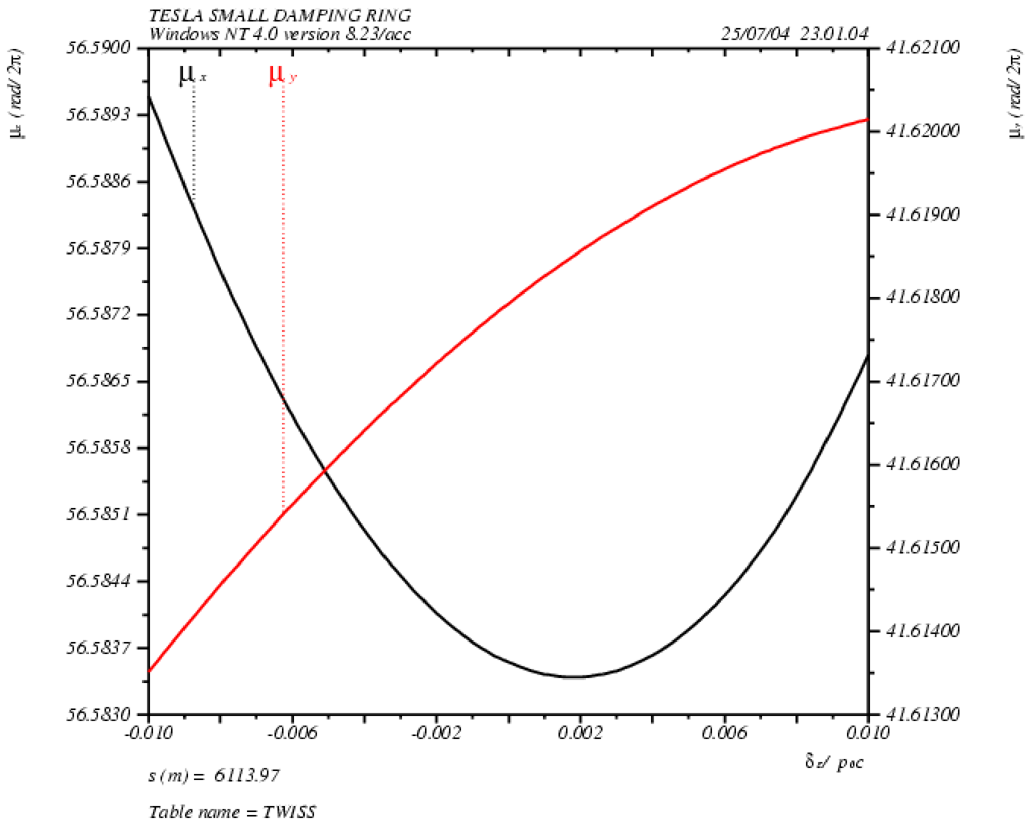


**Figure 8: Betatron tunes vs. momentum deviation**

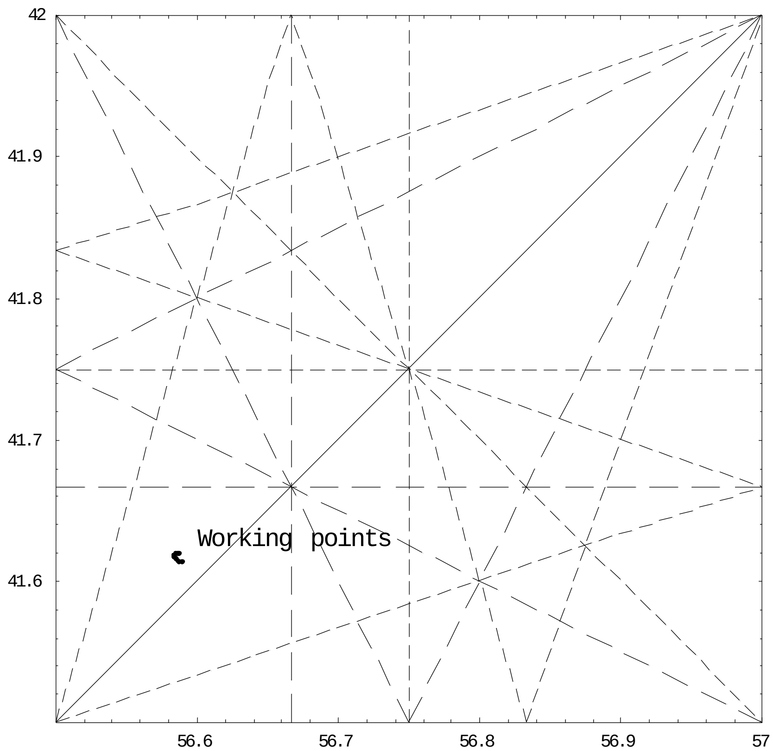


**Figure 9: Working point in tune space. Resonance lines up to forth order are show**

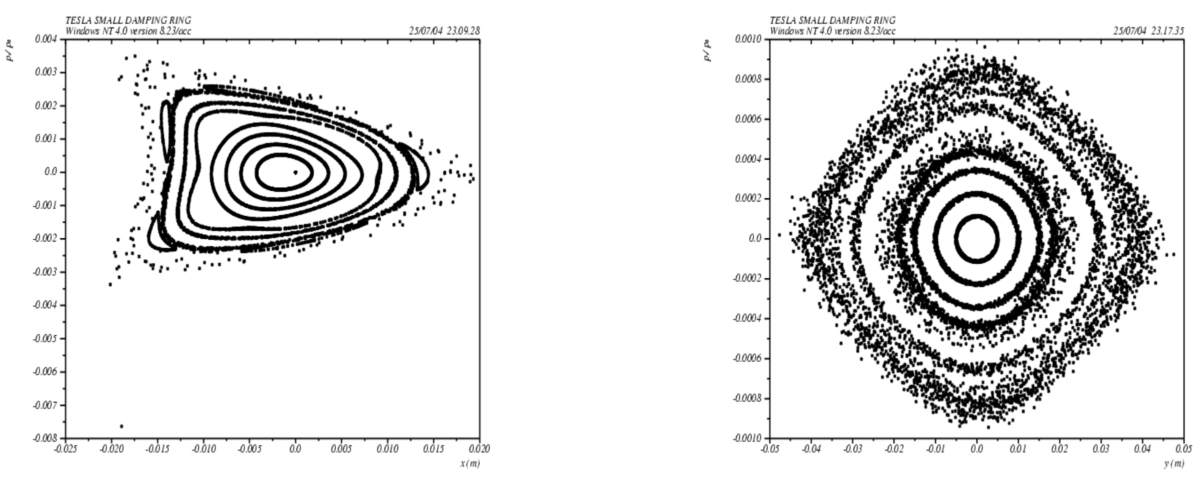


**Figure 10: Phase space plot (Particles have been tracked for 1024 turns.)**

**(a) Horizontal, beta_x = 5.4 m; (b) Vertical, beta_y = 42 m**

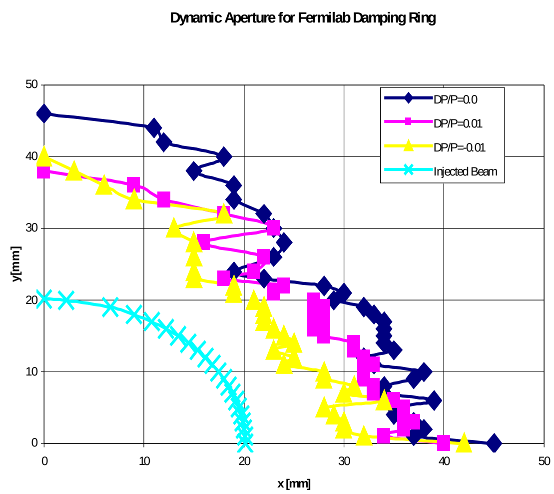


**Figure 11: Dynamic aperture of the ring (beta_max=45m).**

**(The injected beam line is correspond to an acceptance of $9\gamma\varepsilon_{inj.}$, i.e. 3$\sigma$ )**

# 5 Summary of Results and Further Work

An alternative damping ring lattice design for TESLA is presented in this report. The main design criteria have been met. The chromaticity properties and dynamic aperture with linear wiggler effects has also been studied.

In the future, we will concentrate our efforts on beam instability issue and the non-linear effects of wiggler. The misalignment effects on effective vertical emittance will be carried out and the detailed lattice function at injection/extraction area will be designed accordingly.

# Acknowledgements

This work is upon the first primary design from J. Rogers from Cornell. A. Wolski provided us his wiggler model for NLC damping ring design, and very helpful discussion on various topics of damping ring design. Thanks to S. Mishra, G. Gollin, K. Ng, F. Ostiguy for helpful discussions and comments.

# References

[*] Private communication with Dr. J. Rogers.
[1] P. Emma and T. Raubenheimer, "A Systematic Approach to Damping Ring Design", Phys. Rev. ST Accel.Beams 4:021001, 2001.
[2] TESLA Technical Design Report.
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[4] L. C.Teng, Fermilab Report No. TM-1269, 1984.
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